CHAPTER 13

ALTERNATIVE BONE GRAFT MATERIALS

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At present, bone is the most frequently transplanted human tissue other than blood. It is estimated that more than 100,000 bone grafting procedures are performed each year in the United States. Several different types of bone grafts have been investigated for use in bone grafting procedures. Autogenous grafts (isografts) are obtained from the same host, most commonly utilizing the iliac crest. Allografts are taken from a host of the same species, whereas xenografts are obtained from a host of a different species. Due to the immunologic response mounted by the host, xenografts are no longer used as a source of bone graft material. It is generally accepted that autogenous bone is the ideal material for most bone grafting procedures. However, there are significant disadvantages associated with the use of autogenous bone, namely donor site morbidity, and limited supply at any one harvest site. Complications have included continued pain at the donor site, infection, sensory disturbance, hematoma, stess risers, and increased time for recovery. Recently, there has been a dramatic increase in concern regarding the possibility of transmission of the HIV and hepatitis viruses with the use of allograft materials as bone grafts. It was for these reasons that researchers investigated synthetic bone graft materials to obviate the need for a donor site, in addition to providing a suitable cancellous graft alternative. There are several advantages to the use of these synthetic materials including easy storage, unlimited supply, and no risk of disease transmission. Patients receiving alternative graft materials benefit from the lack of an additional surgical incision to harvest the graft, therfore, decreasing anesthesia and operative time.

Autogenous cancellous grafting provides three primary elements for bone remodeling. There is a passive function of osteoconduction (providing a scaffold for vascular and bony ingrowth), an active function of osteoinduction (stimulation of new bone formation by the conversion of mesenchymal cells into osteoprogenitor cells), and osteogenesis (bone production due to the transfer of viable osteoprogenitor cells). However, synthetic bone grafts offer only the passive function of providing an osteoconductive scaffolding, with no inherent osteogenic or osteoconductive properties.

INDICATIONS

There are many procedures where bone grafts are needed. Examples include the augmentation of osseous defects (created by trauma or from the resection of tumors or cysts), treatment of delayed unions or nonunions, facilitation of arthrodesis, and various reconstructive procedures. However, there is no one graft that is most appropriate in every situation. In each of these instances, use is made of one or more of the three previously described functions of the graft, and the surgeon must determine which function of the graft is of prime importance. For example, in an atrophic nonunion of the first metatarsal, osteogenesis is the most important consideration, and fresh autogenous cancellous bone with viable osteoprogenitor cells is the most appropriate material. However, for packing simple bone cysts, an osteoconductive scaffolding is the primary goal and certain synthetic graft materials have been shown to be as effective as autogenous bone. Therefore, the requirements of the specific grafting situation dictate the type of material that should be used.

Synthetic materials are meant to be used as substitutes where cancellous bone would normally be indicated. They are very brittle and have little inherent stability. Therefore, procedures requiring significant stability at the reconstruction site (Evans calcaneal osteotomy) are most often grafted with cortical or cortical-cancellous bone grafts. Today, there are several alternative bone graft products available for use in foot and ankle surgery. These include hydroxyapatite (derived from sea coral), tricalcium phosphate, and composite materials.

HYDROXYAPATITE

The inorganic mineral component of bone consists of deposits of calcium phosphate, which is extremely similar but not identical to the mineral hydroxyapatite [$Ca_{10}(PO_4)_6$ $(OH)_2$]. Synthetic (coralline) hydroxyapatite is produced by the chemical conversion of the calcium carbonate exoskeleton of sea coral into hydroxyapatite. Hydroxyapatite is inert, owing to its lack of organic material and calcium carbonate. It is extremely biocompatible and has not been shown to produce inflammatory or immunologic reactions in the human host. Another advantage of hydroxyapatite is its ability to bond directly to newly formed bone without an interposing fibrous tissue layer. The physical composition of hydroxyapatite is very similar to human cancellous bone, having pores that are completely interconnected and of a very uniform diameter. There are currently two forms of coralline hydroxyapatite available, coralline hydroxyapatite-Porites (CHAP), and coralline hydroxyapatite-Goniopora (CHAG). Each is derived from a different genus of sea coral. Although lacking osteoinductive and osteogenic potential, hydroxyapatite provides osteoconduction when placed in osseous defects.

Coralline Hydroxyapatite-Porites (CHAP)

Coralline hydroxyapatite-Porites, is derived from the exoskeleton of a common reef-building coral, genus Porites, found in the south Pacific Ocean. CHAP possesses a pore diameter of 230μ with interconnecting fenestrations of 190μ (Fig. 1). It has a columnar structure and demonstrates the greatest amount of compressive resistance along the axis of the columns.

In initial studies, CHAP was compared to corticocancellous grafting for repair of cortical defects. However, follow-up studies revealed that CHAP demonstrated inferior ingrowth of trabecular bone. These results led to the investigation of other types of coral for use in orthopedic procedures. CHAP is marketed under the trade name of Interpore 200, by Interpore International, Irvine, California, and is available in blocks of various sizes and shapes. It is still commonly used in maxilofacial surgery.

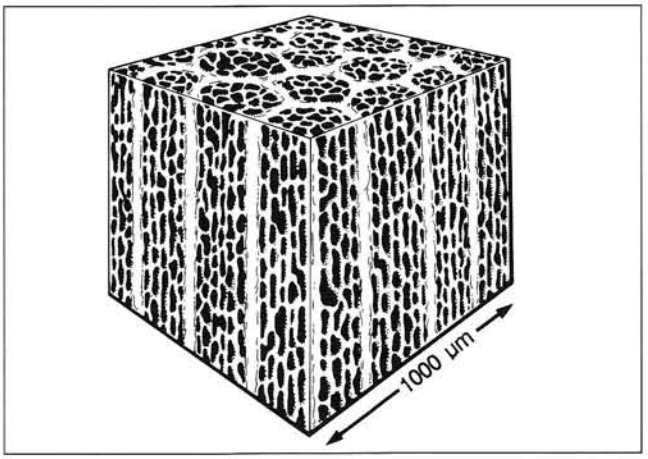

Figure 1. CHAP. Coralline Hydroxyapatite Porites

Coralline Hydroxyapatite-Goniopora (CHAG)

Coralline hydroxyapatite-Goniopora, in comparison to CHAP, has a larger pore diamter and is remarkably similar in structure to human cancellous bone. It has interconnecting fenestrations of 220-260μ and pore diameters ranging from 500-600μ (Fig. 2). The interconnecting network of fenestrations of this material serves as a pathway for neovascularization in the augmentation of bony defects.

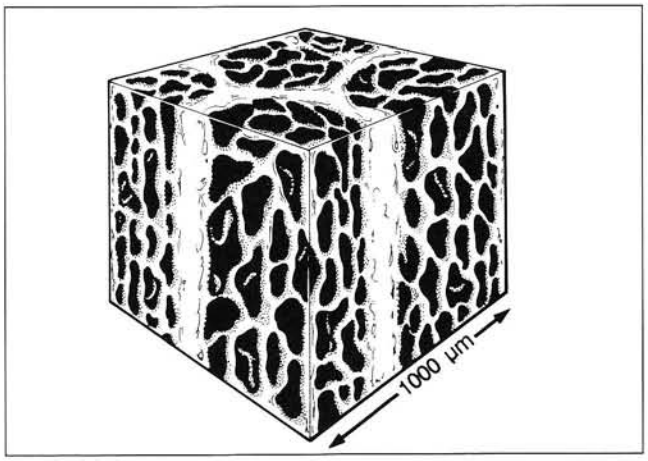

Figure 2. CHAG. Coralline Hydroxyapatite Goniopora

Studies have compared this material to autogenous concellous bone for the filling of metaphyseal defects in tibial plateau fractures. Follow-up clinical evaluation and radiographic assessment showed no significant difference between the two groups. There was obliteration of major fracture lines in 2-3 months in both groups. There were no non-unions and the average depression of the articular surfaces were approximately equal. CHAG's lack of elasticity makes it ideal for filling subchondral defects. It provides greater

structural support, thus decreasing the chance of damage to the overlying cartilage. Although this material biodegrades at a very slow rate in humans, no adverse side-effects have been reported secondary to its persistence.

In its free state, CHAG's compressive strength is less than that of cancellous bone - 55% when oriented parallel to its columnar axis. However, CHAG's ultimate strength has been shown to be three times that of cancellous bone at six months post-implantation. CHAG is also marketed by Interpore International.

TRICALCIUM PHOSPHATE

Tricalcium phosphate (TCP) is produced by heat-fixing betatricalcium phosphate powder at 2000 degrees Centigrade. The particle size ranges from 0.4 to 2μ and has a pore diameter of 250 to 400μ. Marketed under the name Orthograft by DePuy Company of Warsaw, Indiana, it is available as a powder or block form.

Various studies have shown TCP to have a compressive strength comparable to cancellous bone. Like CHAP and CHAG, tricalcium phosphate does not possess osteoinductive or osteogenerative properties. It works by providing an osteoconductive scaffold for vascular ingrowth and new bone formation. In contrast to hydroxyapatite materials, tricalcium phosphate is rapidly degraded in vivo.

Clinical and radiographic results from studies using TCP in filling bone defects created by curettage of benign tumors and cysts, have shown it to be comparable to autogenous bone without the detrimental effects of the harvest. TCP is currently indicated for the filling of small and moderate-sized defects of cancellous bone. Contact with host bone, good vascular supply, and an infection-free site are required for the use of TCP, CHAP, and CHAG.

COLLAGRAFT

Collagraft is a compound containing purified fibrillar collagen (PFC) and hydroxyapatite/tricalcium phosphate ceramic (HA/TCP). It is supplied as a paste or in rectangular block form. It is reconstituted in saline, then mixed with autogenous bone marrow before implantation. The marrow may be obtained from the donor's iliac crest, fracture site, or other area. This type of bone graft material is indicated for use in osseous defects to provide a matrix for bone remodeling. Although Collagraft may be used alone, it can be mixed with autogenous bone to serve as a cancellous graft extender. This is important in cases where autogenous bone is considered to be most appropriate, but the amount that can be obtained is limited. This is often the case in children and in the elderly. Collagraft cannot be used in the presence of local infection, or in patients who have demonstrated an allergic response to bovine collagen. Collagraft has been shown to perform as well as autogenous bone in the treatment of long bone fractures that require bone grafting as a necessary addition to the surgical plan.

CONCLUSION

Although autogenous bone grafts include all three elements of bone remodeling, the absence of osteoinductive and osteogenerative properties has not shown to be problematic in the use of alternative graft materials in certain situations. Hydroxyapatite and tricalcium phosphate possess osteoconductive properties that allow for neovascularization and the ingrowth of new bone. They have proven to be biocompatible, chemically stable, and are easily sterilized and stored. Studies comparing the properties of CHAG, CHAP, and TCP, have shown that CHAG promotes earlier bone regeneration, whereas TCP was found to be the most biodegradable. The use of alternative bone graft materials can spare the patient potential complications associated with the donor site, while providing an effective means of repairing certain bony defects.

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